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AD-A034 049

EQUIPMENT FOR APPLYING PLASMA ARC-HOT WIRE WELDED OVERLAYS ON PROJECTILE BODIES FOR ROTATING BANDS

FRANKFORD ARSENAL, PHILADELPHIA, PENNSYLVANIA

AUGUST 1976

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FA-TM-76047

EQUIPMENT FOR APPLYING PLASMA ARC-HOT WIRE WELDED OVERLAYS ON PROJECTILE BODIES FOR ROTATING BANDS

by

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ADA034049

August 1976

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MM&T Project No. 5736403

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER FA-TM-76047	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EQUIPMENT FOR APPLYING PLASMA ARC HOT WIRE WELDED OVERLAYS ON PROJECTILE BODIES FOR ROTATING BANDS.		5. TYPE OF REPORT & PERIOD COVERED Technical Research Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) ROGER P. STANTON RICHARD S. SCHLAUCH HARRY J. ADDISON, JR.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS FRANKFORD ARSENAL Attn: SARFA-PDM-P PHILADELPHIA, PA 19137		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS CODE: 4932.05.6403 DA PROJECT: 5736403
11. CONTROLLING OFFICE NAME AND ADDRESS ARMCOM		12. REPORT DATE August 1976
		13. NUMBER OF PAGES 39
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

rotating band
plasma-arc welding
welded bands
non-ferrous rotating bands

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report deals with the design and construction of a production type plasma arc-hot wire (PAHW) banding machine. The machine was constructed under contract and employs the PAHW process to apply ferrous or nonferrous overlays for rotating bands to large caliber projectiles. The machine is also equipped with a projectile chucking and rotating mechanism, loading and unloading station, oscillator mechanism, power supplies, appropriate timing (programming) and machine controls, and projectile and torch assembly cooling systems.

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INTRODUCTION

Spin stabilized projectiles normally have either swaged bands or welded overlay rotating bands of copper or gilding metal. In applying a swaged band, the band is pressed directly into a machined band seat. The welded overlay band requires no seat and provides a secure bond through its welded interface. This permits the design and use of thin walled projectiles (as has been done in the development of the 155mm M483 and 8 inch M509).

Welded overlays have been applied in production using the gas metal arc welding (GMAW) process. This process has been used effectively throughout the development of the overlay for a number of different projectiles. However, the Plasma Arc-Hot Wire (PAHW) welding process when introduced to the commercial market, appeared to have a number of advantages over GMAW for the overlay band application. The PAHW process was developed by Linde Corporation primarily for cladding large diameter, heavy walled vessels in the petroleum and nuclear industries.[1] Reported advantages of the process were high metal deposition rates and very low dilution levels. These are desired characteristics of the overlay band operation. Also, because of certain inherent operational features as contrasted with the GMAW process (principally the lack of a moving consumable electrode) it seemed likely that arc (plasma) stability might be more easily maintained; thus possibly reducing the skills needed to assure a consistent and reproducible operation. By adapting the process to banding, it appeared that certain technical advantages could be expected along with accrual of significant cost savings.

The purpose of the project, therefore, was to adapt the PAHW process to the application of ferrous and nonferrous overlays for rotating bands and evaluate its performance relevant to existing equipment for production operations. A production type machine was constructed under contract with the Taylor-Winfield Corporation and equipped with the PAHW process. The equipment also included a projectile holding and rotating mechanism, water cooling tubes for projectile cooling, a timing (programming) system, and an oscillator and appropriate controls. The experience gained in automating the GMAW process for banding[2] was employed so that the shell rotating and weld timing mechanisms, etc., would represent the latest "state-of-the-art". A lesser machine would have introduced extraneous variables and presented serious problems in conducting a valid comparison between the two welding processes, (i.e., PAHW and GMA).

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[1] E.C. Garrabrant and R.S. Zuchowski, Plasma Arc-Hot Wire Surfacing, Linde Electric Welding Library, Phamphlet Number 52-556.

[2] Roger P. Stanton, Kurt Ritthaler and Irving G. Betz, "Equipment for Applying Welded Overlay Rotating Bands of Iron and Other Materials on Ammunition", Frankford Arsenal Memorandum Report M70-28-1, September 1970.

This report describes the automatic welded overlay banding machine utilizing the PAHW welding process. The work was conducted under U.S. Army Manufacturing Methods and Technology Program AMCMS 4932.05.6403; Project Number 5736403. The evaluation of the machine, operational procedures and the properties of the deposited ferrous and nonferrous overlays was performed under MM&T Project 5746403 and will be reported under that project.

PLASMA ARC-HOT WIRE PROCESS

The PAHW process consists of two independently controlled systems operating together to form the weld puddle by melting and fusing the filler metal as an overlay on the steel substrate. A simplified illustration of a projectile being overlayed is shown in Figure 1. In one system two filler metal wires (hot wires) are fed at a constant speed by wire drive rolls to intersect in the arc zone produced by the second system. The wires are electrically connected in series and energized by an a-c constant potential power supply. Ideally, sufficient resistance heating occurs in each wire between the wire contact tips and intercept (weld puddle) causing the wires to form the puddle and melt in it. Input power is selected for a given filler metal feed rate so that maximum resistance heating is induced into both wires without resulting in an open arc between them.

The second system consists of the plasma-arc torch connected in a conventional manner to a constant current d-c power supply. The plasma-arc is initiated by applying a high frequency voltage between the electrode and constricting nozzle. The voltage ionizes the helium-argon gas mixture forming a conductive path to the work (projectile) for the transferred arc current. This form of initiation is illustrated by the pilot-arc cord shown in Figure 1. The high frequency voltage terminates when the plasma-arc current begins to flow through the electrode. Other gas shielding also is employed. Argon is passed through a gas lens system to shield the weld puddle and hot wires. Argon also is passed through the trailing shield to extend the area of protective coverage.

The torch provides additional heating to sufficiently elevate the substrate temperature allowing fusion of the puddle to the substrate thus controlling dilution. Using the plasma-arc as the main energy source for this process, heat transfer and arc force reportedly can be controlled with a high degree of accuracy.

Rotation of the work is counter clockwise with the filler metal wires trailing the plasma torch with respect to rotation direction.

EQUIPMENT DESIGN, CONSTRUCTION AND OPERATING FEATURES

General Features

The PAHW overlay band machine was designed and constructed for automatic operations such as would be required in production. However, manual flexibility was also provided making it possible to adjust and experiment with various parameters so that their affect on performance could be studied and appropriate procedures established . The selection of manual or automatic operation was controlled by a master selector switch.

Figure 2 is a plan view of the machine showing provisions for disassembly of the main support columns which permitted moving the equipment through confined areas during installation at Frankford Arsenal. An increase in machine cost and a decrease in some rigidity were experienced because of this requirement but these were not of sufficient magnitudes as to warrant concern. The dimensions are as indicated.

An effort was made to build good control and consistency into the machine. However, no effort was made to alter or modify any of the PAHW components. The commercial welding package was used without modification except for slight changes in bracket designs for hanging the equipment on the machine.

Figures 3 through 13 and 15 through 18 (along with a Code Sheet) show the major parts and features of the machine. These include the welding equipment (PAHW), its various parts and power supplies, the oscillator and projectile chucking and rotating mechanisms, projectile loading and unloading station, projectile cooling tube and electrical controls, timers, safety devices and indicators.

Projectile Loading-Unloading Station, Chucking Mechanism and Rotating Mechanism

Projectile Loading-Unloading Station - The projectile loading-unloading station (1) shown in Figure 3 receives shell which are introduced to the station by manual (hand) loading. The projectile is loaded from the front (operator's position) of the machine on the cradle containing roller supports.

Upon activation of the start sequence, the cradle is drawn into the plane of the chuck centerline. The elevator (2) lifts the projectile from the cradle to a predetermined height set by adjustment of a screw thread on the elevator. Position adjustments of the roller supports and the lifting arms on the elevator are made by loosening nut and bolt clamping devices located in machined slots.

Projectile Chucking Mechanism - A precision chucking arrangement (3 in Figure 3) positively and consistently locates, aligns, and holds the projectile beneath the welding torch for overlaying. The distance from the floor to the centerline of the chucked projectile is about 47 inches to provide for easy observation of and access to the overlay by the welding operator.

The machine also has a control and gage for setting and determining the loading pressure behind the moveable chucks to permit adjusting the loading pressure for different projectiles. Pneumatic cylinders activate both chucks but pressure valves and gages allow the tailstock (left chuck in Figure 3) to overcome the right chuck and come to a positive stop, thus consistently and accurately positioning the projectile beneath the torch. When the projectile is unchucked, both head and tailstock retract eliminating hangup of the shell as it is lowered on the elevator to the cradle below. The head and tailstock tooling are bolted in place and can be replaced rapidly when another type of shell is to be overlayed. The equipment is designed so that bands can be applied within ½ inch of either end of the projectile with full and effective gas shielding.

Projectile Rotating Mechanism - The machine is capable of rotating the projectile both clockwise and counter-clockwise at any selected speed between ½ min/rev and 5 min/rev. Precise timing for the projectile turning mechanism is provided by a tachometer feed-back drive system. The projectile drive motor (5 in Figure 4) and rotating mechanism reach the selected speed within 0.5 sec and stop in less than 1^{o} at the highest speed. The return to the start position for applying the next overlay is accomplished by reversing direction until a stop is triggered by the upper cam (6) in Figure 4.

Welding Equipment

Plasma Torch Assembly - The torch assembly (9, 10, & 11 in Figure 5) consists of a plasma torch, two hot wire contact tips and block assembly, an inert gas shield inclosure with trailing shield, viewing ports, gas hoses, water cooling hoses and a mounting arm and pivot bracket assembly. All of these features except for the water cooling hoses and pivot assembly may be seen from the underside of the torch assembly as shown in Figure 6.

The torch is of the constricted arc type and has a capacity of 750 amperes at 100 percent duty cycle. It is connected in a conventional manner to a constant current DC power supply (See Power Sources, Page 8). A constricted arc torch is used because it permits precise control of the heat transfer and arc force.

The operator can position the electrode prior to or during surfacing by means of a pivot and horizontal adjustment mechanism that is provided.

A relatively large gap (about 3/4 inch) between the electrode tip and work (See Figure 7) provides the necessary clearance for introduction of the hot wires and their manipulation in the arc zone. Orientation of the two hot wires or filler metal nozzles with respect to the torch is shown in Figures 6 and 7. The filler metal extension, or wire stickout, is normally about 1½ inch.

Approximately 55 cfh of a 75 percent helium - 25 percent argon gas mixture is passed through the torch orifice to support the transferred arc. Thirty to sixty cfh of argon gas is passed through the concentric gas shield located at the lower end of the torch and protects the molten puddle and hot wires. Another 30 to 60 cfh of argon gas is dispersed beneath the water cooled 4 x 6 inch rectangular trail shield to give additional protection to the overlay and hot wires. However, for the most effective control of overlaying it was found that the direction of projectile rotation needed to be reversed from that normally employed. Therefore, the trail shield does not provide as extensive coverage for the deposit as envisioned by the process developer. Nevertheless, it was not a determining factor in the quality of the product.

The inert gas inclosure (10 & 11 of Figure 5) is suitable for shielding large caliber projectiles such as 155mm and 8 Inch. It has large observation ports made of No. 12 filter lenses on both forward sides of the assembly and is equipped with an asbestos skirt that fits snuggly around the shell. The filter lenses are replaceable. The factory supplied ports cracked repeatedly from radiation during initial overlay tests and were quickly covered by zinc vapor when gilding metal overlays were deposited. The right port (11 in Figure 5), therefore, was modified at Frankford Arsenal to view the overlay effectively. The new right viewing port (Figures 5 to 8) being some two inches further removed from the arc is less prone to crack and is much less subject to zinc oxide buildup.

<u>Dual Roll Wire Feeder</u> - This wire feeder (12 in Figure 9) is used to pull either 1/16 or 3/32 inch diameter filler wires from two 12 inch diameter wire spools mounted on spindle assemblies (13 in Figure 10). The feeder is capable of pushing the wire from 50 to 600 inches per minute through the flexible conduits (15 in Figure 9) to the hot wire contact tips in the trailing shield assembly. Feed rolls and contact tips are provided for both 1/16 inch and 3/32 inch diameter wires.

<u>Wire Straighteners</u> - Between the wire feeder and rotary spindles are mounted two rotary wire straighteners (14 in Figure 10) for the hot wires. The straighteners[3] are adjustable for handling 1/16 and 3/32

[3] F.W. Hussey, "Wire Straighteners for Arc Welding", Welding Journal, September 1963.

inch diameter filler wires. Rotation is in the approximate range of 2000 to 3500 RPM. The straighteners automatically commence rotating when the wires start feeding and stop when the wire feeder is de-energized.

Wire Feed Counter - A wire counter (20 in Figure 9) is provided for reading or monitoring the total amount of hot wire feed during overlaying to a least measure of 0.1 foot. Accuracy is within 0.25 foot/100 feet of wire. The pickup wheel (20 in Figure 9) for the wire measuring system is located between the wire drive (12) and the wire straightener (14). As the wheel (20) turns, a signal registers in tenths of feet on the wire indicator instrumentation (See 21 in Figure 15).

Oscillator Mechanism - The oscillator and its various components are seen in Figure 11. The slide (33) supporting torch and trail shield, the arm (34) supplying the force, the motor (located behind arm) that moves the slide, and the switch (35) used to signal that the oscillator is at mid-stroke make up the main components of the oscillator mechanism. This switch stops the oscillating torch near the mid-point of the overlay rather than allowing it to stop in a random location. If the torch were to stop at the edge of the overlay, the edge might be too low because of increased deposit fluidity resulting in an overlay that could not be machined into a finished rotating band. The machine is capable of striking and extinguishing the arc within 1/4 inch of band center due to a built in automatic coordination between the electrical circuit and oscillator movement. However, it is possible to by-pass this feature to permit welding without it and to allow manual start and stop of the oscillation. The latter is needed to locate the oscillation with respect to the band seat location, to measure oscillation width and to permit manual positioning for welding as might be required for repairing overlays.

The oscillation mechanism and mounting brackets permit the welding torch to be driven through a reciprocating pattern producing a sine wave displacement with respect to time. The oscillator is capable of any width of oscillation between zero and 2½ inches and any frequency up to 80 cycles/minute. When the oscillator is set, locking features prevent any further change in oscillation width or frequency that could otherwise result from vibration or jarring during subsequent welding operations. The oscillation motion is horizontal and parallel to the centerline of the chucked projectile so that the distance between the base of the torch and guide wire tips and the top surface of the shell along the plane through the projectile's centerline remain within $\pm$ 0.010 inch runout within a 2½ inch oscillation width. The mounting and drive arrangements are such that the wire relationship of the two filler wires to one another will not change, i.e., both wires remain in their exact relative positions regardless of oscillation movement.

Power Sources and Electrical Brushes

DC Power Supply for Plasma Torch - The DC welding power supply (18 in Figure 12) is a transformer-rectifier of the type normally employed with

the PAHW process. The unit has a rating of 1000 amperes at 100 percent duty cycle and is adjustable from the control panel by employing a current adjust motor with range switches.

AC Power Supply for Heating Wires - The AC welding power source (19 in Figure 12) is a constant voltage unit with a 40 volt open circuit capability, of the type normally used in PAHW welding and has a capacity of 500 amperes at 100 percent duty cycle.

Electrical Brushes - A set of two electrical brushes (36 in Figure 3), rated at 600 amperes for continuous operation are located near each chuck. Both sets provide positive electrical conductivity for completing the welding circuit. It is necessary that brush assemblies be covered to avoid contamination from dirt, spatter or other environmental particles.

Structural Supports and Adjustments for the Welding Equipment and Power Sources

The welding torch assembly is mounted so that deposition can take place on the surface of the chucked rotating projectile as shown in Figure 5. The torch assembly and associated components including the wire feeder, counters, and straighteners have a simple lateral position adjustment to permit overlaying at any position along the length of the projectile (up to 36 inches). Originally a screw drive turned by a hand wheel was supplied to move the torch along the axis of the shell but operating the wheel manually proved to be fatiguing. A power drive shown as Item 22 of Figure 13 was then added by the contractor. Small adjustments along the projectile axis are made by turning the hand crank (23 in Figure 3) supplied with the standard Plasma Hot Wire package.

Considering the X axis the centerline of the projectile through the chucks, the Y axis in the vertical direction through the projectile centerline and the Z axis through the machine (front to back), the torch and associated components are mounted so as to permit adjusting the torch between 0° and 20° on both sides of the Y axis in the Y-Z plane with the torch nozzle in the direction of the pivot point (X, Y, Z: 0, 0, 0). The entire torch-hot wire feeder system is mounted on a saddle arrangement supported by two four inch diameter bars the ends of which are mounted in brackets. The brackets move in machined slots on bearings as shown in the front and end view drawings of Figure 2. Figure 13 shows the bracket (24), slot (25) and the screw drive (26) to pull the entire arrangement through the $\pm 20^{\circ}$ requirements. A chain (27) connects the screw drive to an identical system on the other side of the machine so that no binding or cocking will occur.

The plasma torch and associated dual wire feeder, counters and straighteners can be raised up to 6 inches above the centerline of the chucks along the previously mentioned angle made by the saddle arrangement. The heavy duty slide (29 in Figure 10) supports all of the welding apparatus, i.e., torch assembly, wire feeders, straighteners, etc. and provides the capability to move the torch and gas trail shield mount up or down along the angle to change the distance between the torch and workpiece (projectile surface). This movement is fixed during welding and is independent of the arc voltage control movement that will be covered later.

The wire conduit, drive mechanism, counters and straighteners are capable as a unit of a 3 inch maximum horizontal movement perpendicular to the projectile axis that is independent of the previously mentioned "off center" movement. The movement permits an "in" and "out" adjustment of the two wire guide conduits attached to the wire contact tips. The movement is accomplished by the heavy duty slide (Item 30 in Figure 10).

The hot wire mounting brackets, which hold the wire contact tips in position beneath the torch, are of sturdy construction, rigidly mounted to the torch and permit manual screw adjustment of the wires in the vertical and horizontal direction beneath the electrode, from a pivoting position centered immediately behind the torch. The adjustments are made by turning knobs 31 and 32 in Figure 9.

The various screw adjustments are lockable to prevent movement of their slides or assemblies during overlaying or subsequent operations. Also, the mountings for the torch assembly, wire conduits, drive mechanism, counters, wire straighteners, etc., are electrically insulated to prevent short circuiting between components.

The power for the overlaying operation is provided from the DC and AC power supplies stacked in a steel frame as shown in Figure 12 to conserve space.

Timing and Cam Controls

The timing system employed is illustrated in Figure 14 (times and sequence shown approximate a procedure used in depositing gilding metal on the 155mm M483 projectile). Figure 15 shows the timers schematically represented in Figure 14 except that several 10 second timers were later replaced with 30 second timers as shown in Figure 14 (times shown in Figure 15 do not necessarily represent actual overlay settings).

When the projectile is chucked, and the cooling nozzle is in place, all starting timers are actuated (See Figure 14). Projectile rotation and overlay desposition proceed according to the starting timers until the terminal cam on the drive shaft actuates a master timer which in turn actuates the terminal slave timers.

Clock Face Timers - Clock face timers as shown in Figure 15 are used to control the duration of the welding variables. These timers are adjustable, capable of being locked, and are readily replaceable and interchangeable to permit the insertion of other timers of greater or lesser range. The timers were originally capable of resetting and measuring time up to 10 seconds for timers 1-6TD and 8-14TD. The master terminal timer (7TD) is capable of a maximum setting of 150 seconds and timers 15 and 16TD have a maximum duration of 60 seconds. As previously noted, timers 11TD, 12TD, and 14TD were increased to 30 seconds full scale duration to improve the performance of the process in the critical overlap area of the overlay deposit. The least measure for the timers depends on the function and varies from 1/6 second (0.17 sec) for most to 2 seconds for the master terminal timer (7TD). Accuracy of all timers is within $\pm$ 1 percent of full scale.

The cycle terminates according to the terminal timer settings in Figure 14. The complete cycle places the shell beyond the 360° position. In the automatic cycle, when the overlay has been deposited and the plasma arc is extinguished, the cooling tube withdraws and the chucks automatically release the projectile to the load-unload station which then lowers the projectile from the welding position. This latter series of functions is initiated by the torch water off delay timer (16-TD) in Figure 14. Finally, the drive shaft rotates to zero and the "reset" cam instantaneously stops the return rotation at 0°; thus placing the machine in readiness for the next cycle.

The machine also is capable of a manual operation in that after the plasma arc is extinguished according to the timer settings, the subsequent de-chucking and unloading operation may be manually activated. It also is possible to recycle without releasing the chucks. Such controls are desirable for establishing parameters during setup activities.

Arc Timer - The arc timer (38 in Figure 15) on the front panel automatically starts timing when the arc goes "on" and stops when the arc is extinguished. This timer differs from those previously described in that it is a timer and not a controller. The timer does not reset to zero until a new cycle is actuated. It is capable of timing the arc period (deposition time) up to 10 minutes and is readable to 0.001 minutes.

Cams - The terminal cam (lower cam near 6 in Figure 4) is normally located on the drive shaft approximately 340° from start (0°). The cam is adjustable so that its position can be varied at least between 335° and 360°.

Graduations or locating marks are provided every five degrees on the cam and drive shaft to identify the cam position during adjustment. A locking device prevents any further movement after being set.

The "reset" cam (upper cam near 6 in Figure 4) is usually set at 0° of the cycle but is graduated and adjustable permitting a setting of $0^{\circ} \pm 5^{\circ}$. The reset cam is independent of the terminal cam and is locked to prevent further movement.

The cam switches actuating terminal functions and setting the machine for a new cycle are precise and allow no appreciable triggering time variation, i.e., less than $\pm$ 0.25 second.

Machine Controls

The controls employed to deposit PAHW overlays are incorporated into the banding machine's two control panels (Figures 15 and 16) which are readily accessible to the operator at his normal position in front of the machine, and include the fine voltage control on the DC power supply. An emergency "stop" button is centrally and obviously located at the front of the machine for immediate actuation. The button completely shuts off the machine when pushed.

Arc Voltage Control - A device is incorporated in the equipment to automatically control the arc voltage between the torch and the workpiece to a preset value. This device (17 in Figure 15) which provides a five inch adjustment of the torch is an adjusting potentiometer and digital readout meter. It permits setting and automatically or manually maintaining the torch voltage.

Arc Current Controls - A control also is incorporated into the panel in Figure 15 to raise or lower the plasma arc current. This obviously increases or lowers the heat input during overlay deposition. The switch is located in the set of nine switches to the left of the arc voltage control.

Hot Wire Speed Controls - The hot wire is equipped with two feed controls (fast and slow) to provide the appropriate amount of wire for the deposit throughout the overlay cycle. A digital readout, direct reading control is provided for controlling the hot wire "fast" feed (16 in Figure 16). The control (which shows a setting of 300 inches/min) reads one digit/inch of wire feed and will control the feed of 1/16 or 3/32 inch wire. The hot wire "slow" speed control, a potentiometer, is located beneath the "fast" feed control.

Welding Meters - All voltmeters and ammeters in the plasma and hot wire circuits are of the digital readout direct reading type. The digital meters used to measure current and voltage of the hot wires (AC) and the plasma arc torch (DC) are identified No. 39 in Figure 15. The meters

have a non-blinking display and figures are uniplanar making them readable from many viewing angles. Voltmeters have a least measure reading of 0.1V and their circuits have an accuracy of at least $\pm$ 0.25V at full scale of the meter. The ammeters have a least measure of 1 ampere with a circuit accuracy of at least $\pm$ 0.5 ampere at full scale.

Projectile Loading-Unloading Control - The set of buttons shown in the lower right portion of Figure 15 contain the controls for manually directing the transfer and positioning of the projectile prior to overlaying as well as those for projectile unloading and ejection after the overlay is applied. Projectile loading and unloading occur automatically when the switch in the lower mid-portion of the panel is in the automatic position.

Projectile Chucking Control - The previously mentioned set of buttons also contain the controls for manually chucking and de-chucking projectiles. When the switch in the lower mid-portion of the panel is in the automatic position, chucking and de-chucking occur automatically.

Projectile Rotation Control - The projectile rotation speed is selected by a digital readout direct reading control (No. 4 in Figure 15). This control is a thumb wheel potentiometer with a least measure of one second/revolution and is accurate to within $\pm$ 1 percent of the selected timed speed. Readout of the speed is provided by the digital meter immediately above the potentiometer which reads RPM.

Oscillator Control - Controls for setting the frequency of oscillation and dwell time at the end of the cycle are located in the lower left of Figure 16. The width of oscillation is set by changing the length of stroke of the oscillator drive arm (34 in Figure 11). As previously mentioned, the frequency of oscillation can be set up to 80 cycles per minute and the width of oscillation may be set between 0 and 2½ inches. Whether the oscillator is employed manually or automatically is determined by a switch in the set of 9 switches to the left of the arc voltage control (17 in Figure 15).

Manual Control of Operational Functions - As stated earlier, the machine is capable of automatic cycling as diagrammed in Figure 14, but is also equipped with appropriate manual controls to permit independent operation of a number of functions including projectile transfer, chucking, projectile rotation, projectile water on and off, torch oscillation, arc initiation with accompanying slow and fast wire feed and de-chucking and unloading of projectile. Controls also are provided to move the welding torch assembly along the length of the projectile to the site where the overlay is to be applied. On the other hand, a few functions are fixed and cannot be adjusted in this equipment. For example, in the manual mode, the machine is constructed so that the cooling water and shielding gases for the orifice, plasma torch, hot wire torch and trailing shield, flow immediately after the water cooling tube is positioned as shown in

Figure 14. The machine will not permit varying the initiation time of these functions after the water cooling tube is seated since such flexibility is not necessary for the application of PAHW overlays.

Required overlay operations which are adjustable in the machine are listed below. The functions that, by selection, can be automatically sequenced or manually and independently controlled are indicated by asterisks.

a. Projectile is placed in loading station (manual with aid of hoist).

*b. Upon energizing the start button, projectile is raised from loading station for chucking; projectile is chucked.

c. Projectile water cooling tube is moved through chuck into shell.

d. Welding operation is started (the following sequential order would depend on the timer settings).

*Projectile rotation is started

*Wires start feeding

Cooling water and inert gas to welding head components are activated

*Power is initiated to wires	)	...does not function without
	)	inert gas "on" and cooling
*Plasma arc is started	)	water "on" to head com-
	)	ponents

*Oscillation is initiated-

*Projectile cooling water flow is initiated

e. Welding operation is stopped (the following sequential order would depend on the timer settings).

*Projectile rotation (1st stop) is stopped

*Projectile rotation is started

*Projectile rotation (2nd stop) is stopped

*Wire feed (current off) is cut off

*Plasma arc is shut off

*Oscillation is stopped

*Water cooling to shell and retract cooling tube is shut off

*Orifice gas is shut off

*Crater fill, torch and trailing shield gas is shut off

*f. Projectile body is released to loading station located below welding position (will not operate if cooling tube has not retracted).

*g. Chucks are returned to starting position for recycling.

*h. Overlayed projectile is positioned in loading station for convenient manual removal and another projectile is loaded.

As mentioned previously, the "automatic/manual" control switch controls all asterisked functions and determines whether the functions automatically sequence according to the timed program or whether each function must be controlled by independent start-stop (on-off) control switches or buttons. The independent starting or stopping of these functions is determined by actuating start-stop switches or buttons for each function when the master switch is in "Manual" position. This also holds true for the previously described sixteen timers used to control the overlay process. When the automatic/manual switch is moved from the automatic to manual mode, each of the timed functions are initiated by push buttons on the panel in Figure 15. Chucking, unchucking, etc., are also initiated by push buttons.

<u>Cooling Systems</u>

<u>Projectile Cooling System</u> - A water tube and nozzle in the machine provides water to the projectile interior at a flow rate of up to 6 gallons/minute for cooling. The cooling nozzle as it would appear inside a projectile is shown as item 43 in Figure 8 (the plasma torch has been displaced from its normal position to allow a better view of the water nozzle). The cooling nozzle precisely and automatically locates itself within the projectile immediately upon being chucked. The welding torch will not initiate an arc until the nozzle is in position. The water tube and nozzle also automatically retract permitting the projectile to drop out and the next projectile to enter. In the foreground of Figure 18 are spacer elements (42) for positioning the nozzle within the particular projectile being overlayed.

The water tube is capable of being preset for any specific position from zero to 36 inches from the chuck to permit locating the nozzle under the overlay deposit. The water tube is lockable so that vibration and retraction do not affect the preset position of the nozzle and is designed to permit the adaptation of various nozzles which would be required for different projectiles. Water to the tube is supplied by the chiller shown in Figure 17.

A flow meter (40 in Figure 18) indicates the amount of water flow up to 6½ gallons and has a least measure of 1/8 gallon.

Projectile inlet and outlet water temperature is measured by a digital thermocouple indicator (41 in Figure 18) to the nearest one-tenth of a degree F. This instrument which measures from $32^{o}F$ to $200^{o}F$ is superior to a thermometer with respect to readability, accuracy, and durability.

Welding Torch Cooling System - The welding torch is water cooled by a system independent of the projectile water cooling system to prevent a surge in the flow during the various cycling events. A Bernard radiator (37 in Figure 18) provides a pressurized (greater than 100 psi) closed loop cooling system for the plasma arc torch, trailing shield, and hot wire torches as specified and provided by the manufacturer of the plasma arc welding equipment. Distilled water is used to prevent impurities such as mineral deposits clogging the narrow water passages in the plasma arc torch.

CONCLUSIONS

The design and construction of a plasma arc-hot wire overlay band machine was accomplished by means of Army Manufacturing Methods and Technology Project No. 5736403 entitled, "Plasma Arc-Hot Wire Welding Method for Applying Artillery Projectile Rotating Bands".

The design was based on previous experience gained with gas metal arc (GMA) overlay banding equipment. Except for the substitution of PAHW for GMA welding equipment, machine components were either similar to or improved versions of those employed in existing GMA production machines.

One feature of particular interest was a tachometer feed-back projectile drive system to turn the projectile uniformly and consistently during overlaying. This system is less subject to heating and aging, the principal causes of speed variations in the DC motor drives employed in existing machines. Thus, the tachometer control reduces the extent of these variations. Also, its ability to control speed more precisely permits a more efficient change over from one overlay schedule to another.

Another significant improvement in machine controls was the employment of digital meters and digital readout controls for measuring or setting current, voltage and projectile coolant temperature. These have the capability of providing improved weld schedule accuracy and product reproducibility. Finally, the sturdiness with which machine components were constructed and assembled should be assets in a production environment where down time due to components slipping out of adjustment from normal equipment vibrations can be costly.

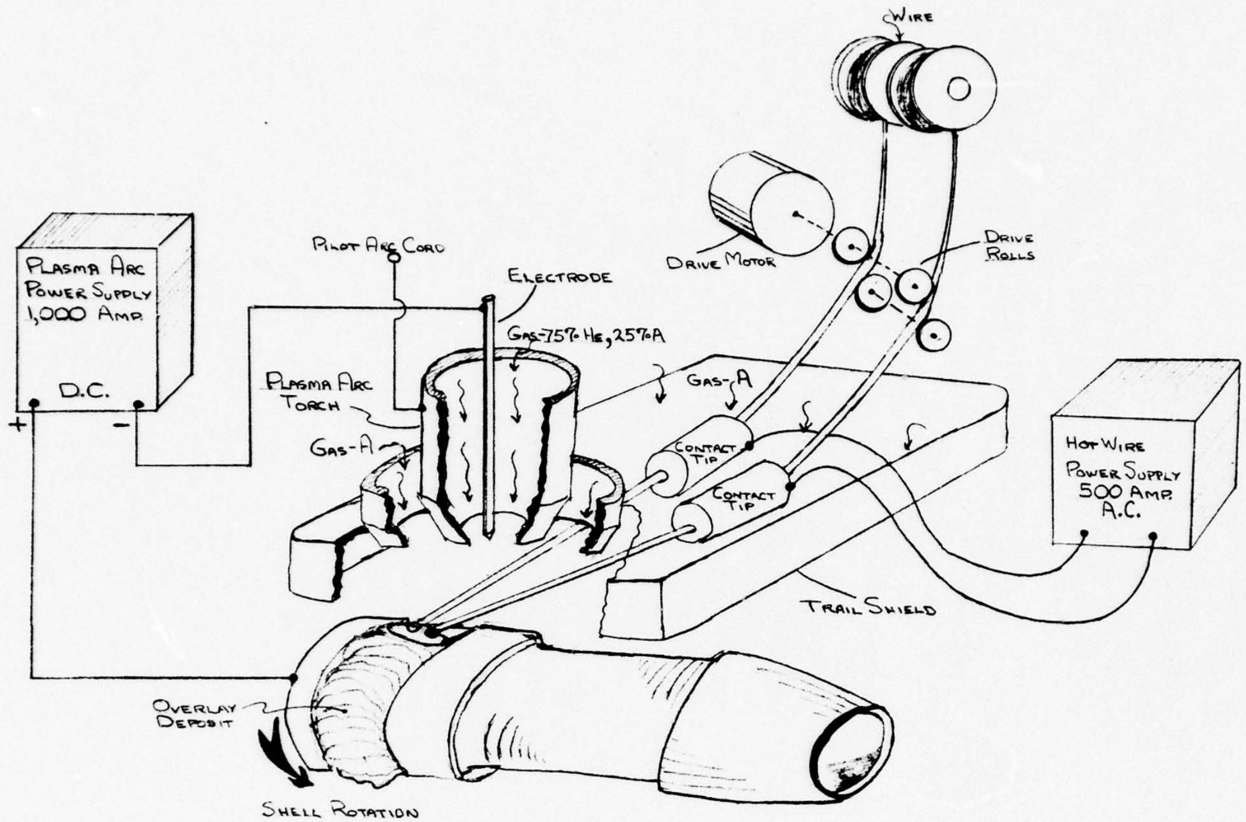


Figure 1. Schematic Representation of Plasma Arc Hot Wire (PAHW) Overlaying of 155mm M483 Projectile.

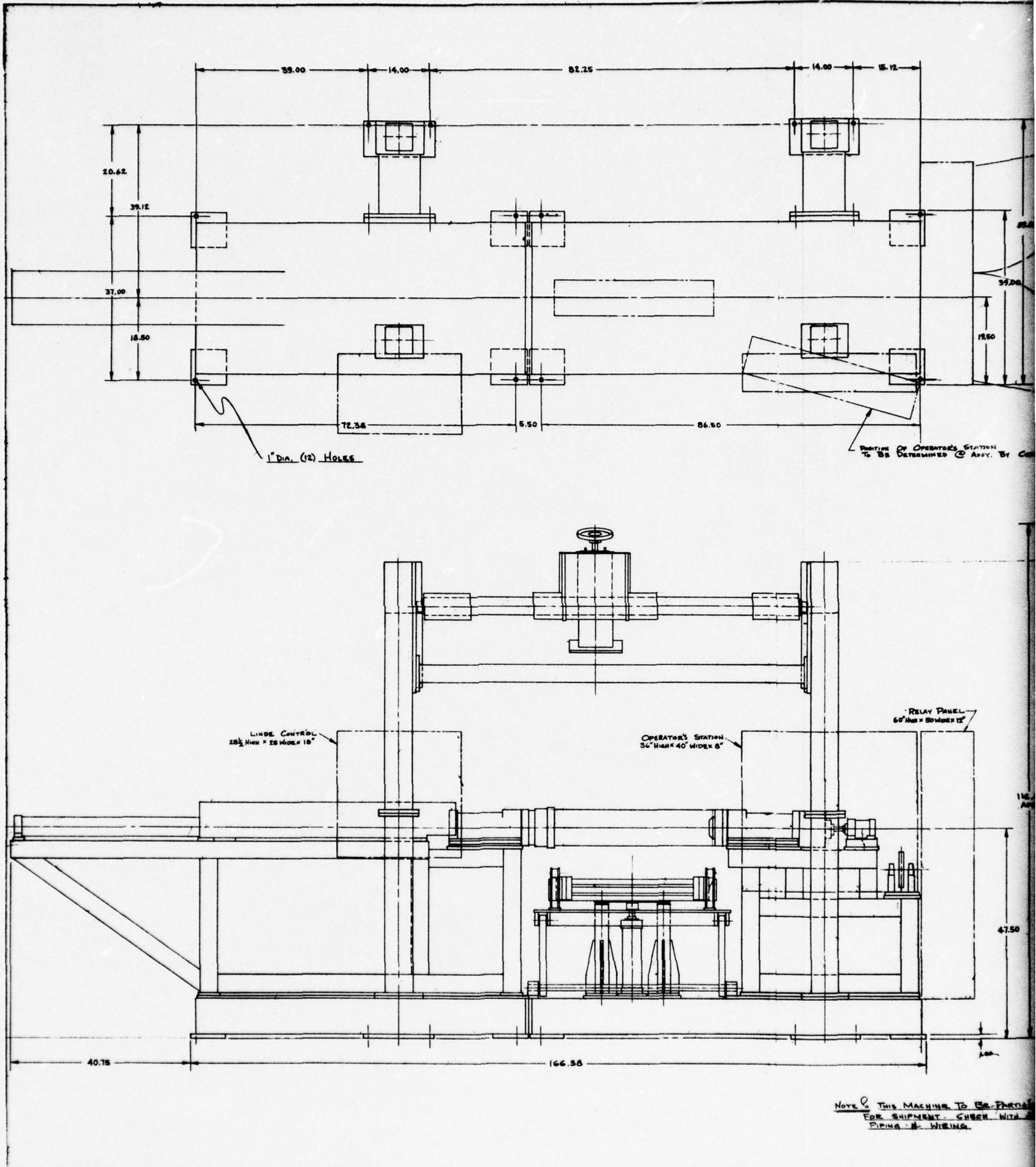
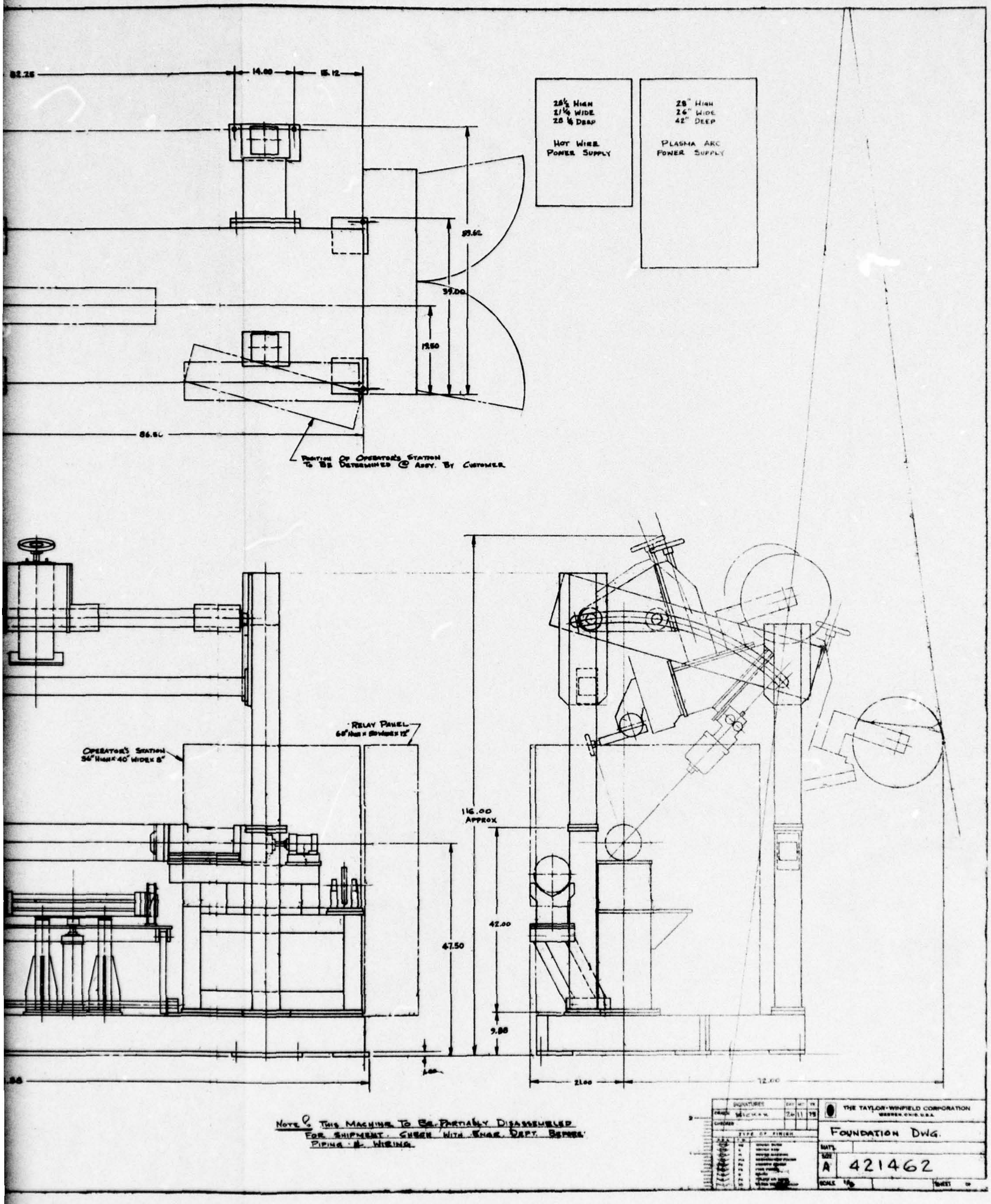


Figure 2. Foundation Drawing of the PAHW Overlay Banding Mach



ation Drawing of the PAHW Overlay Banding Machine

ELEMENTS OF OVERLAY BANDING MACHINE

The numbers listed below refer to elements of the overlay banding machine shown in Figures 3 to 13 and 15 to 18. This list identifies each itemized part in the figures.

1. Roller equipped projectile support cradle.
2. Projectile elevator.
3. Projectile tooling for 155mm projectile.
4. Potentiometer controlling rotation speed.
5. Projectile drive motor.
6. Cam-switch system for start-stop sequence.
7. Air pressure gauge and valve system.
8. Pneumatic solenoids.
9. Plasma torch.
10. Trailing shield enclosure.
11. Modified viewing port.
12. Wire drive mechanism.
13. Wire spindle assembly.
14. Rotary wire straighteners.
15. Flexible wire conduit.
16. Digital hot wire "fast" feed potentiometer.
17. Arc voltage potentiometer and readout meter.
18. Plasma arc power supply, 1000 ampere max. capacity.
19. Hot wire power supply, 500 ampere max. capacity.
20. Wire measuring pickup wheel.
21. Wire measuring indicators.
22. Power drive unit for positioning torch along length of shell.
23. Hand crank slide for moving torch in small increments along length of shell.
24. End bracket for cross-member support.
25. Guide track for moving torch through $\pm 20^{\circ}$ arc.
26. Screw drive to move torch through $\pm 20^{\circ}$ arc.
27. Chain and sprocket connecting right and left screw drive mechanism.
28. Slide assembly controlling "off center" position.
29. Heavy duty slide providing vertical travel.
30. Heavy duty slide providing "in-out" adjustment.
31. Knob for adjusting horizontal movement of hot wires.
32. Knob for adjusting vertical angular movement of hot wires.
33. Oscillator slide.
34. Oscillator drive arm.
35. Mid stroke oscillator signal switch.
36. Electrical brush assemblies.
37. Bernard radiator system.
38. Arc timer.
39. Digital panel meters.
40. Water flow meter.
41. Digital temperature indicator.
42. Water nozzle spacer elements.
43. Shell cooling water nozzle.

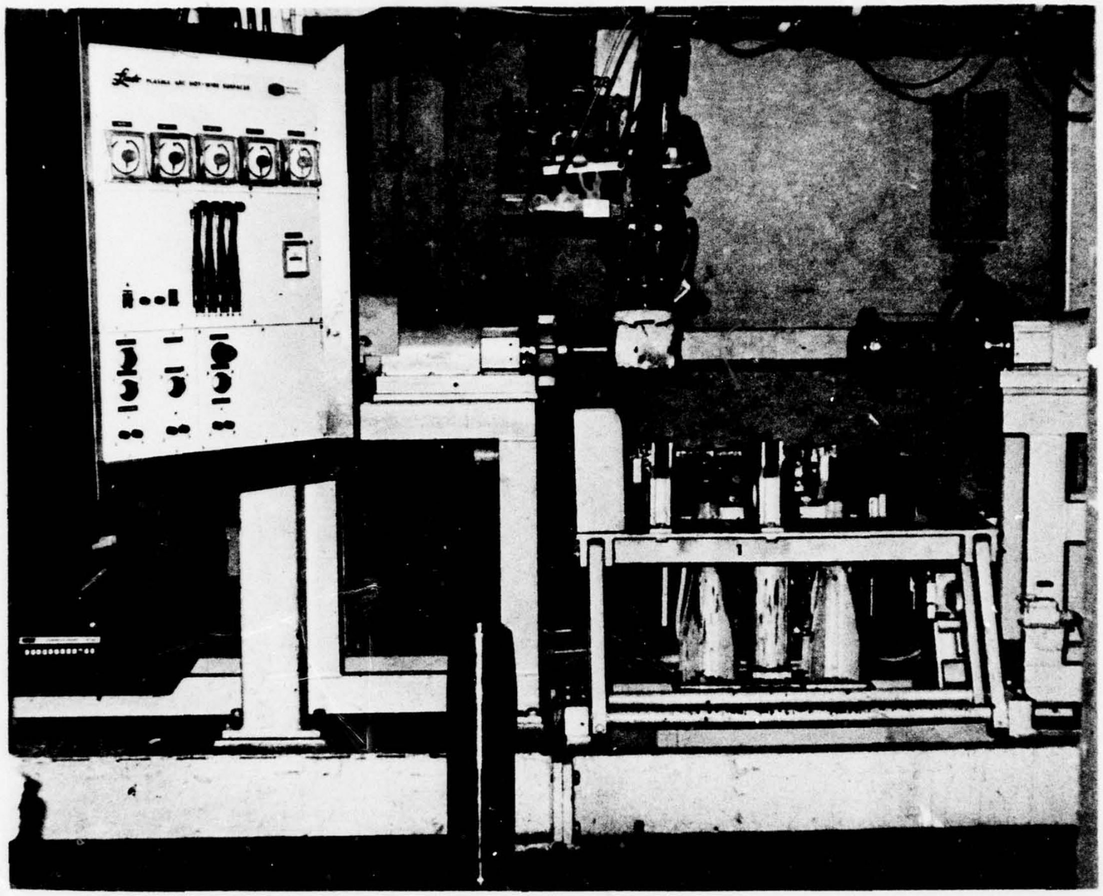


Figure 3. Front View of PAHW Banding Machine Showing Projectile Transport System and Tooling.

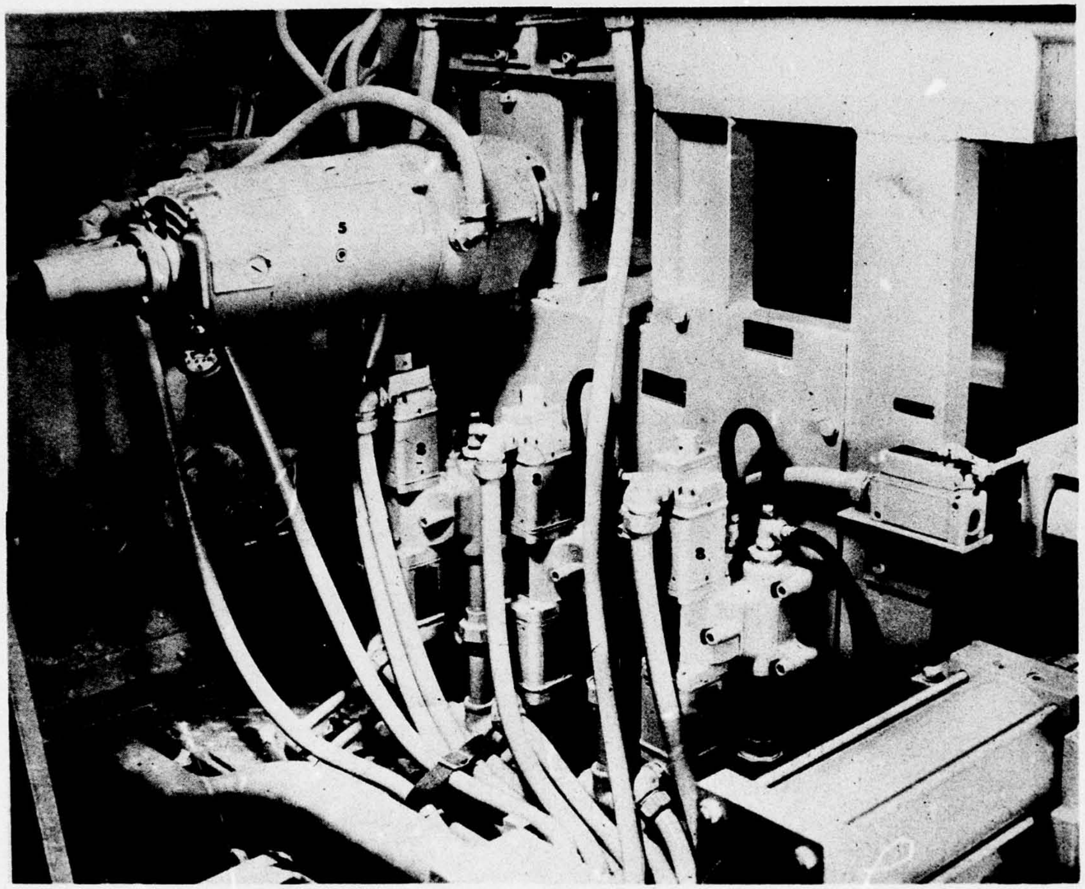


Figure 4. Rear View of PAHW Banding Machine Showing Projectile Drive Motor, Cams, Switches and Pneumatic Control Solenoids.

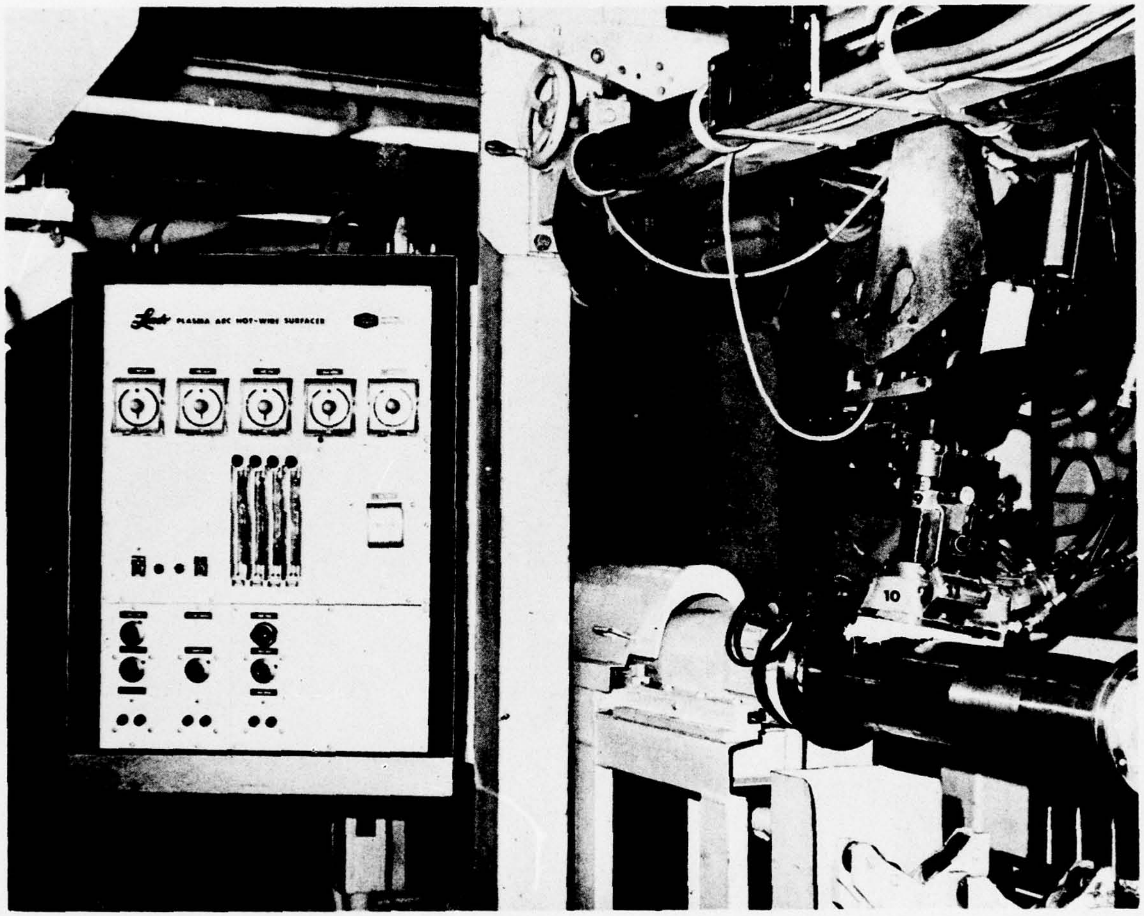


Figure 5. PAHW Torch Assembly with Projectile in Position for Overlaying.

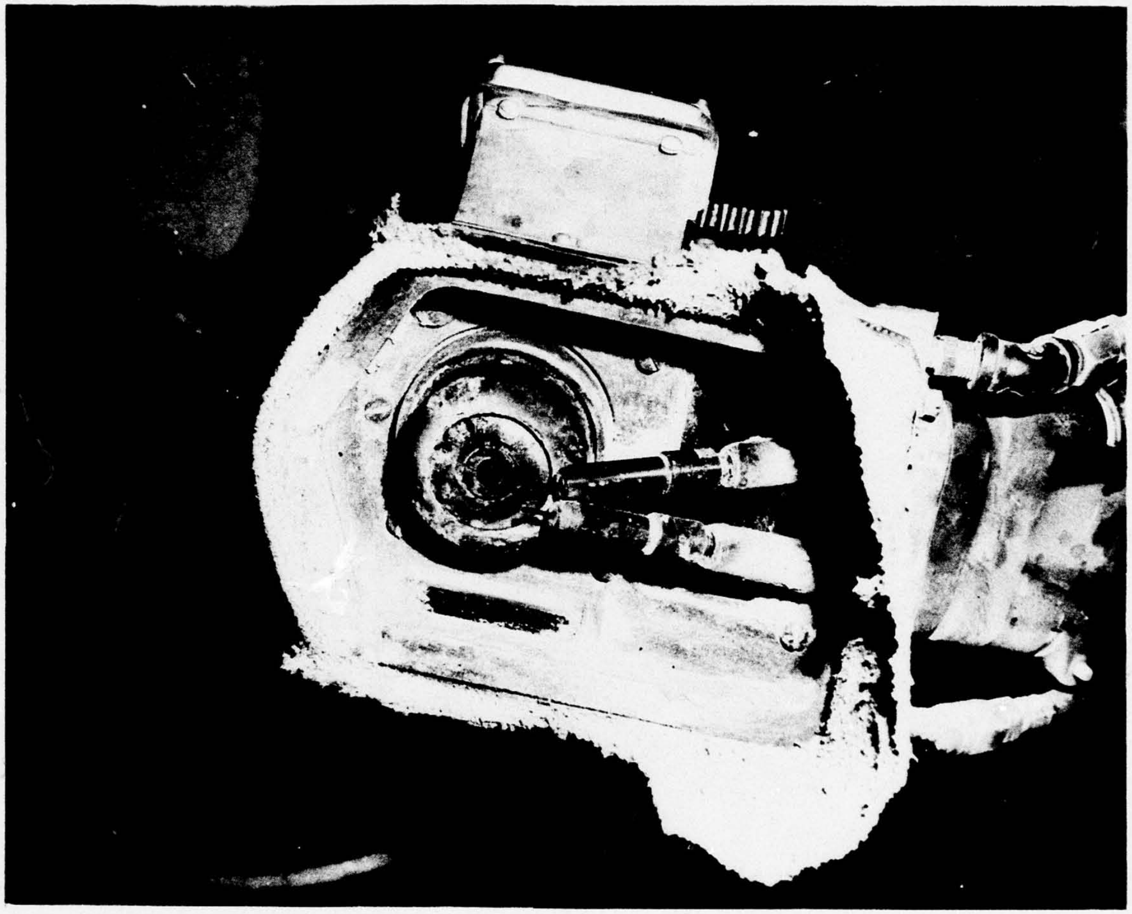


Figure 6. Underside of PAHW Torch Assembly.

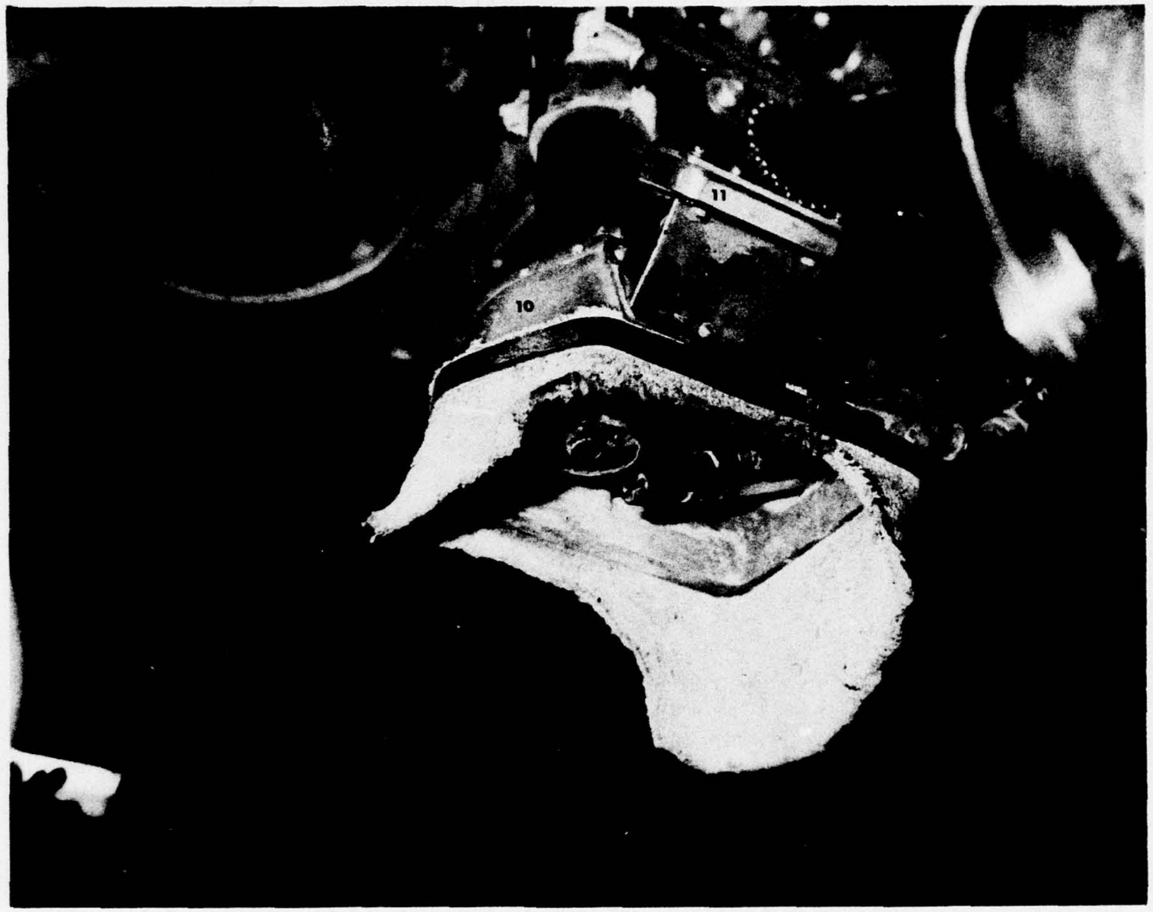


Figure 7. Relative Position of Hot Wires with Respect to Electrode.

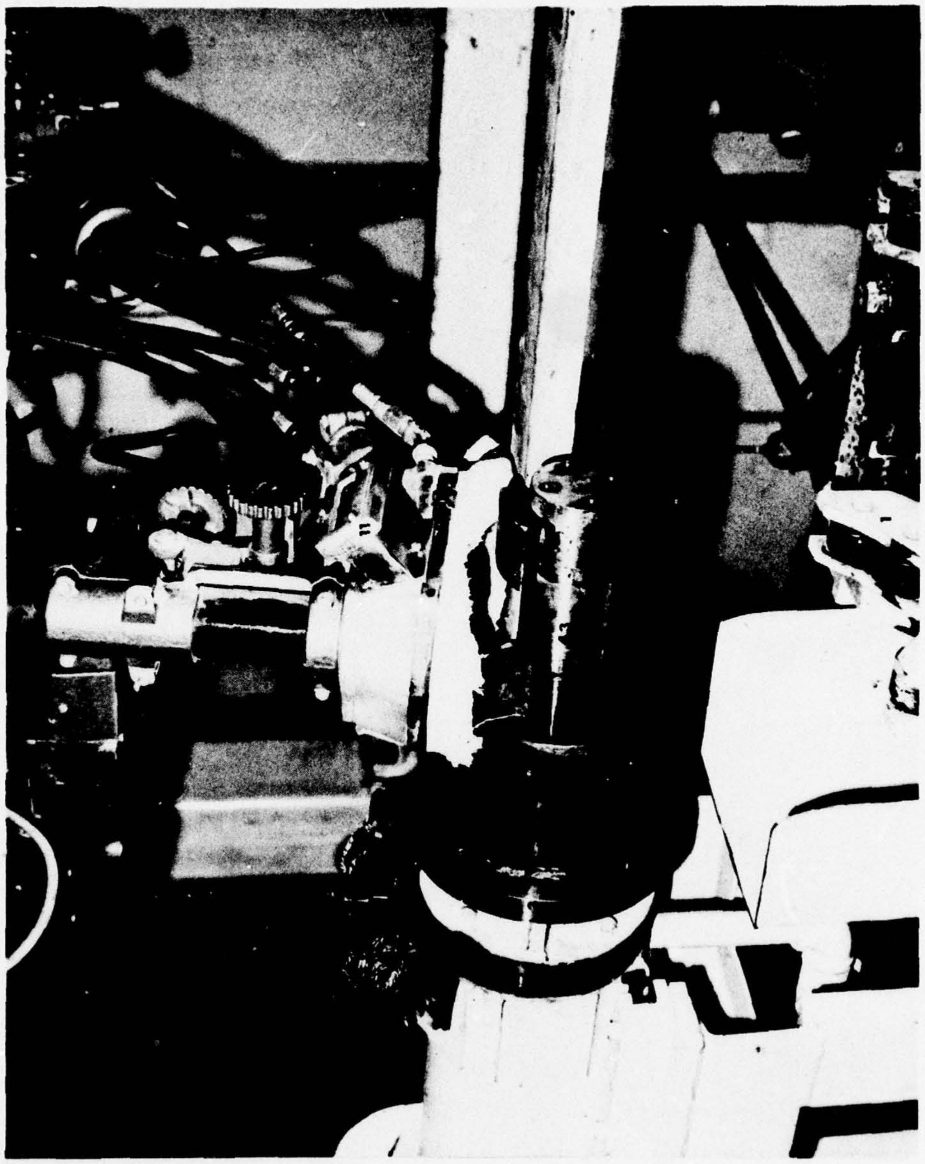


Figure 8. Projectile Water Cooling Nozzle and Set of Current Pickup Brushes.

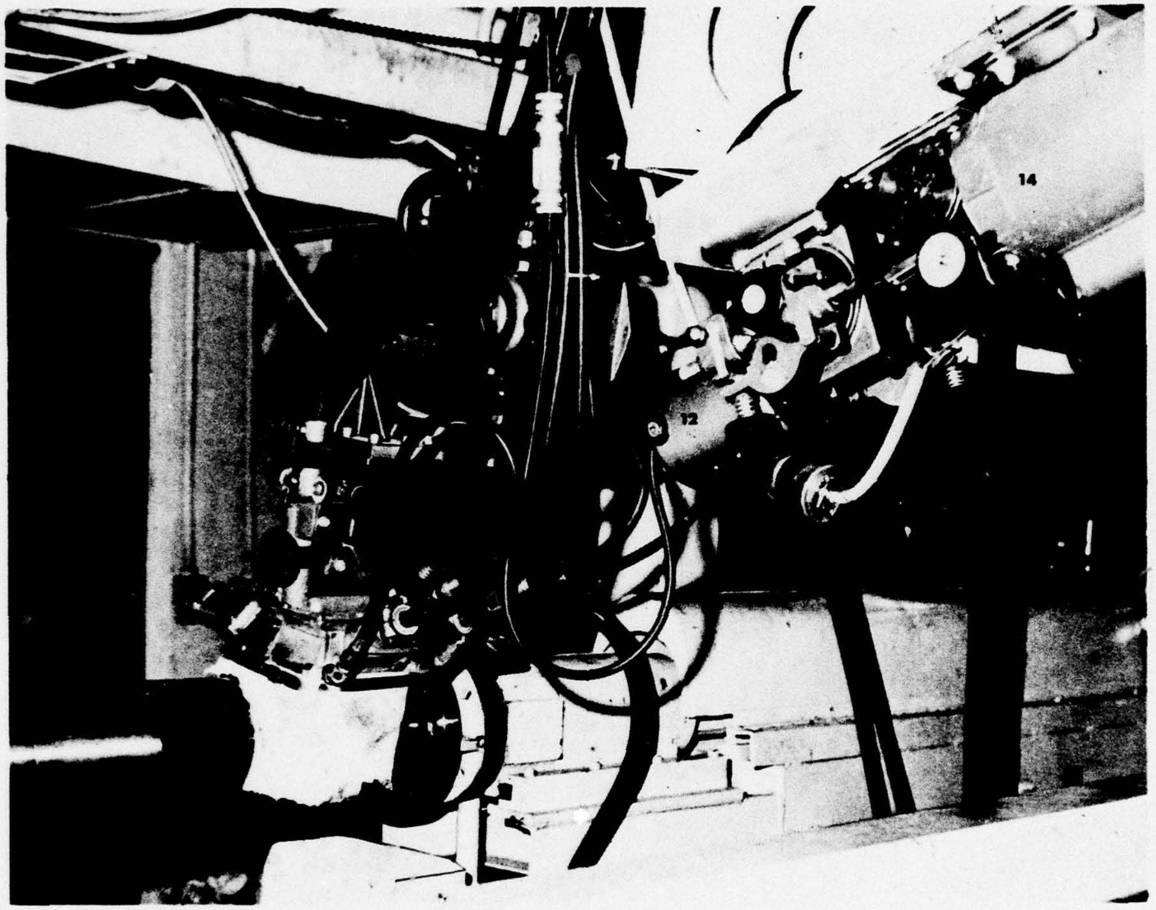


Figure 9. . Rear View of PAHW Banding Machine Illustrating Hot Wire Conduit, Wire Drive, Wire Counters and Wire Straighteners.

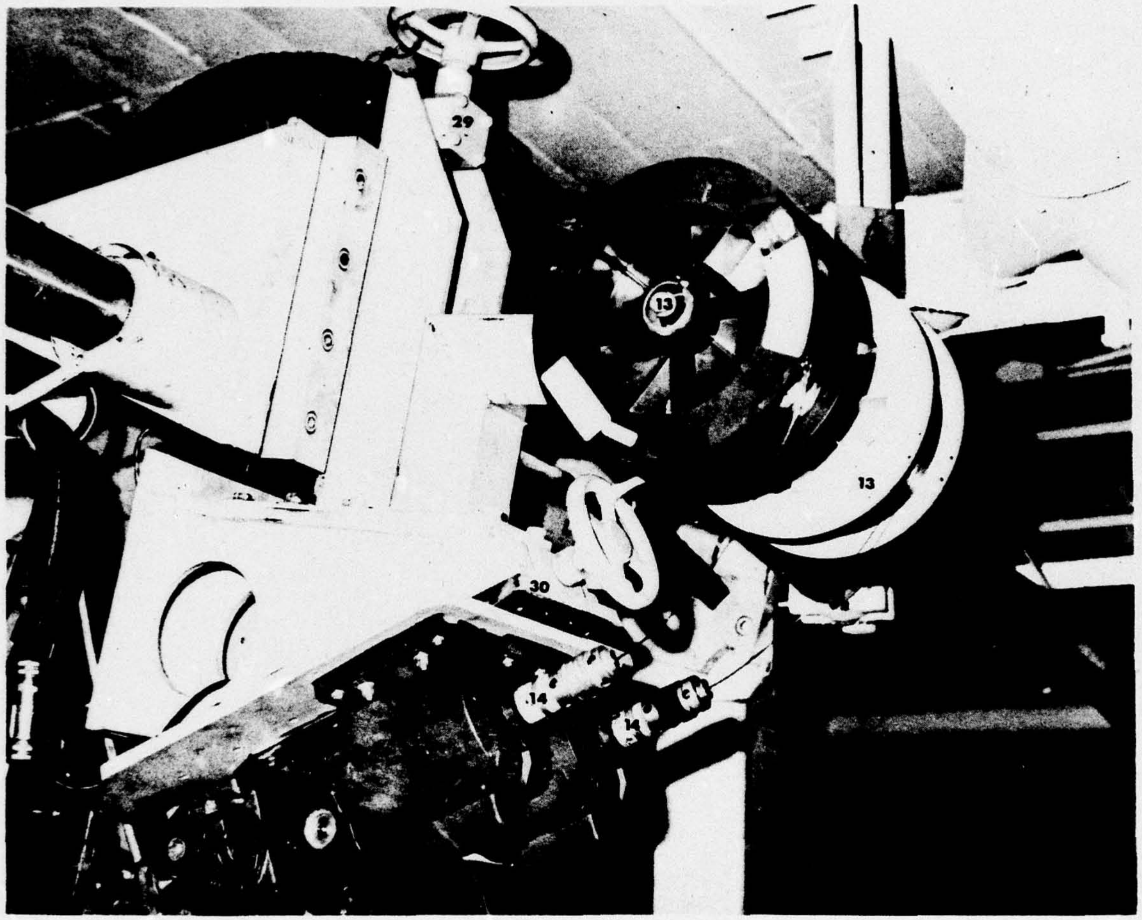


Figure 10. Heavy Duty Slides for Vertical and Horizontal Adjustment of Welding Equipment.

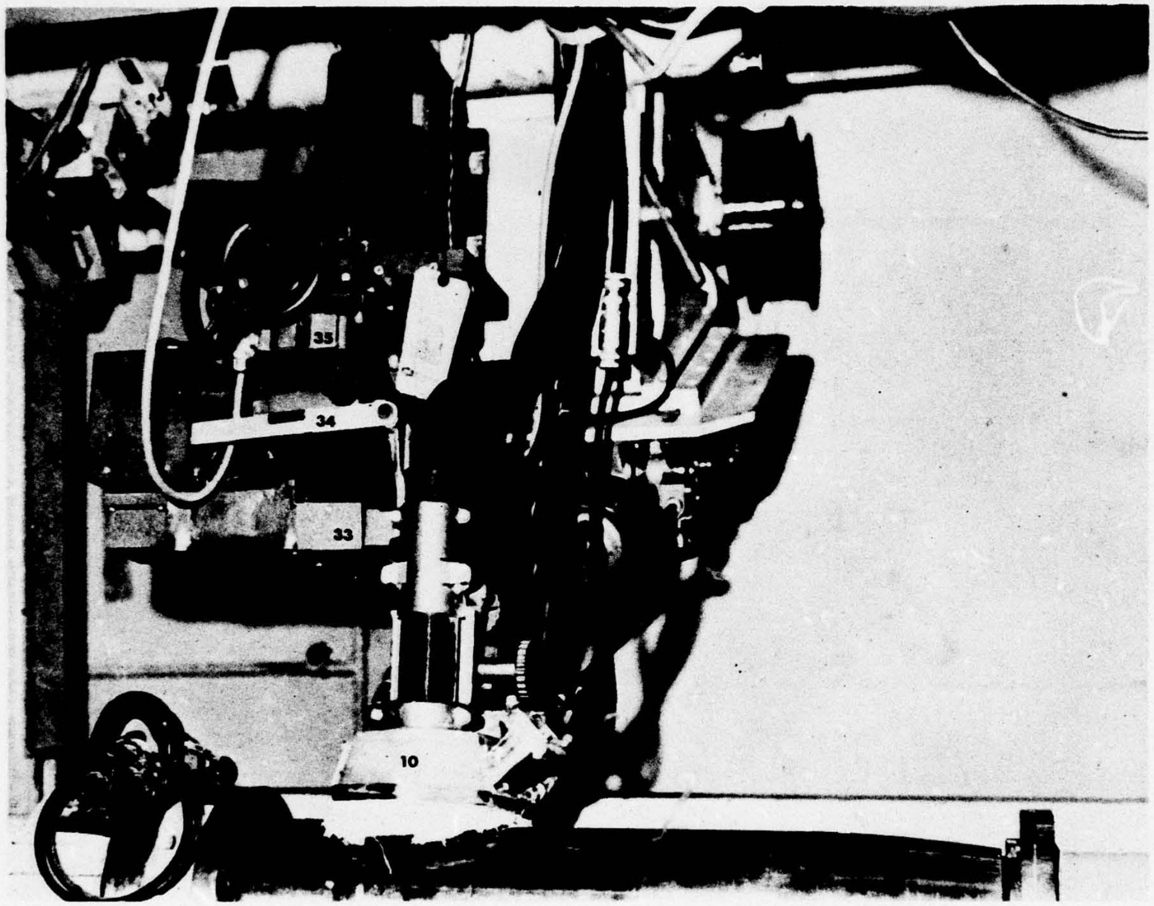


Figure 11. Oscillator Features and Off Center Slide Adjustment for PAHW Torch Assembly.

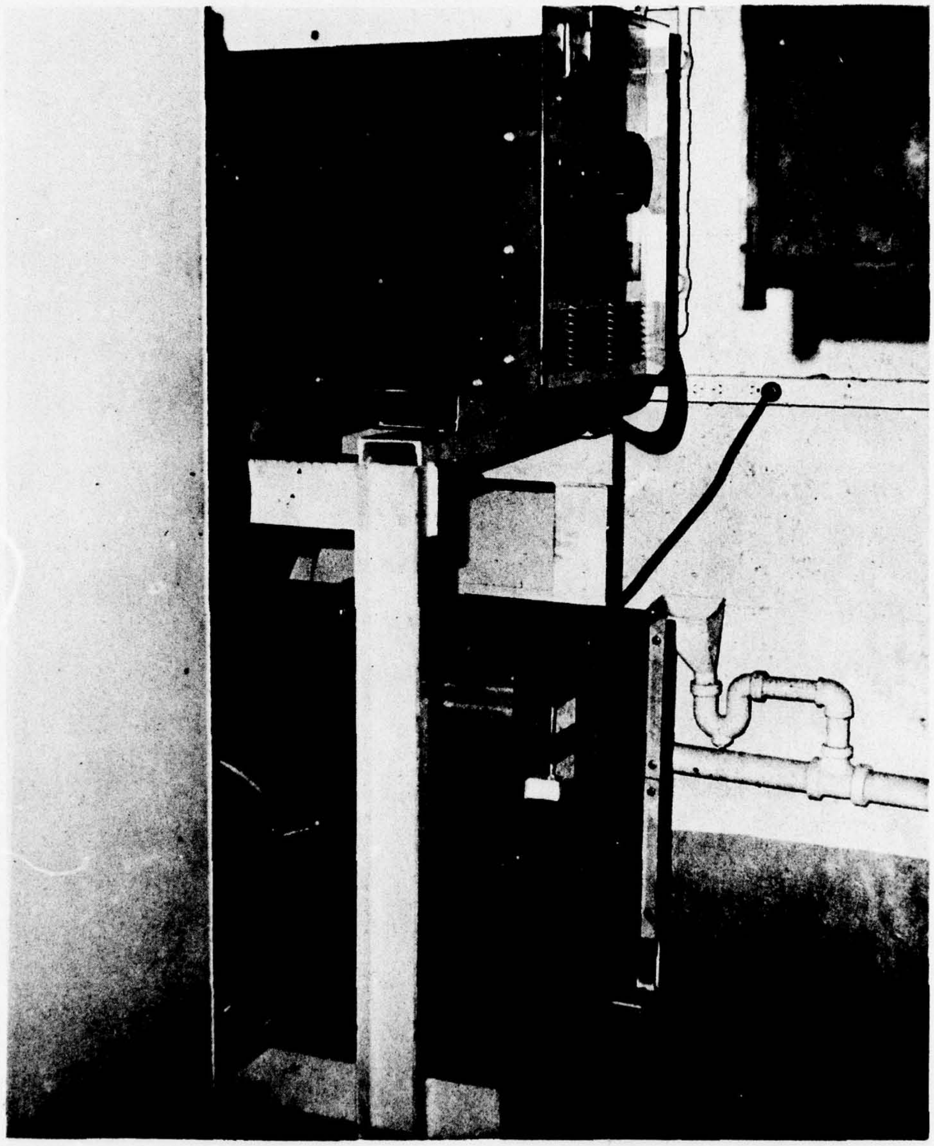


Figure 12. AC Power Supply (top) for Hot Wires and DC Power Supply (bottom) for Plasma Arc Torch.

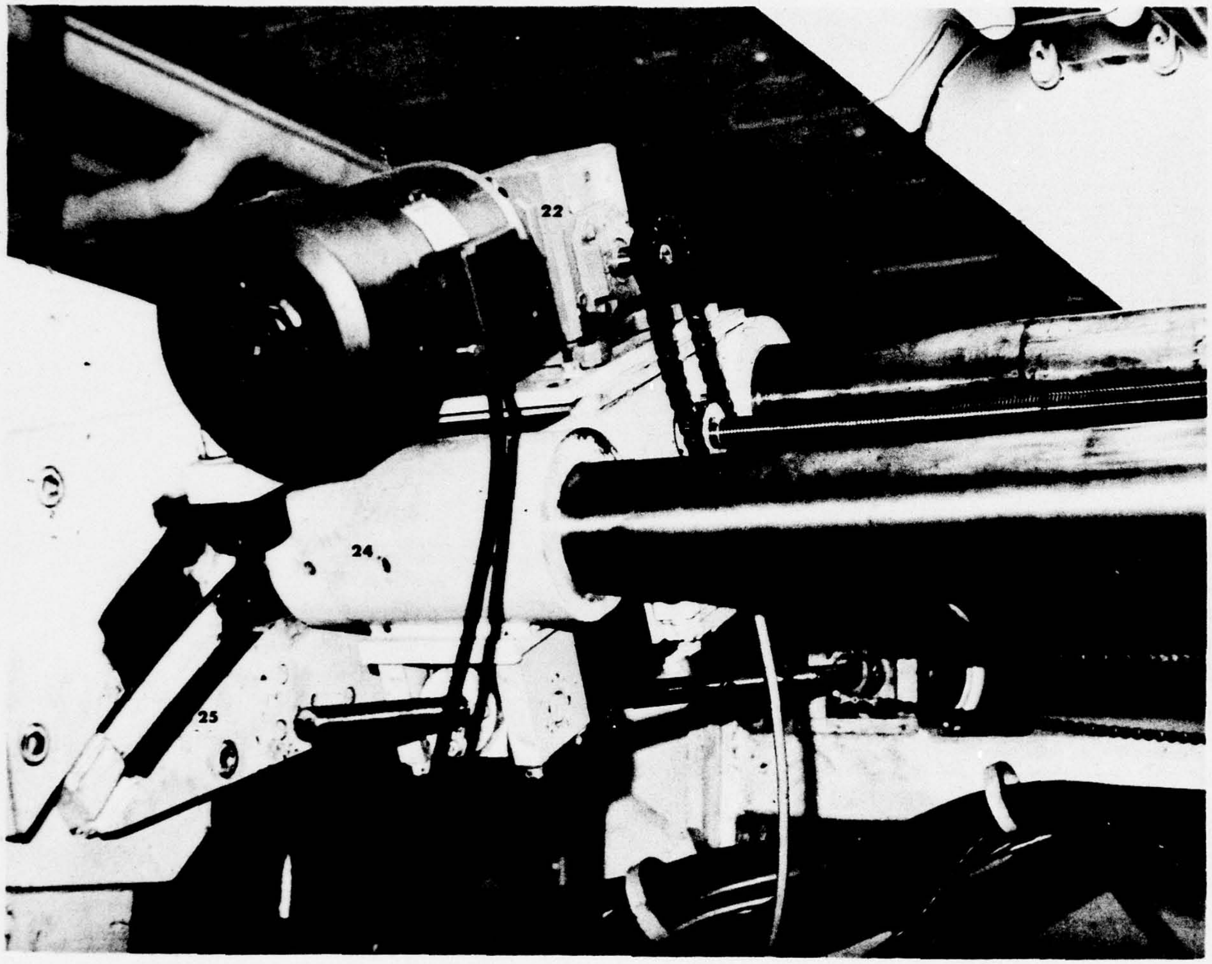


Figure 13. Power Drive Unit for Adjusting Torch Position Along Projectile Length and Manual Screw Drive for Torch Angle.

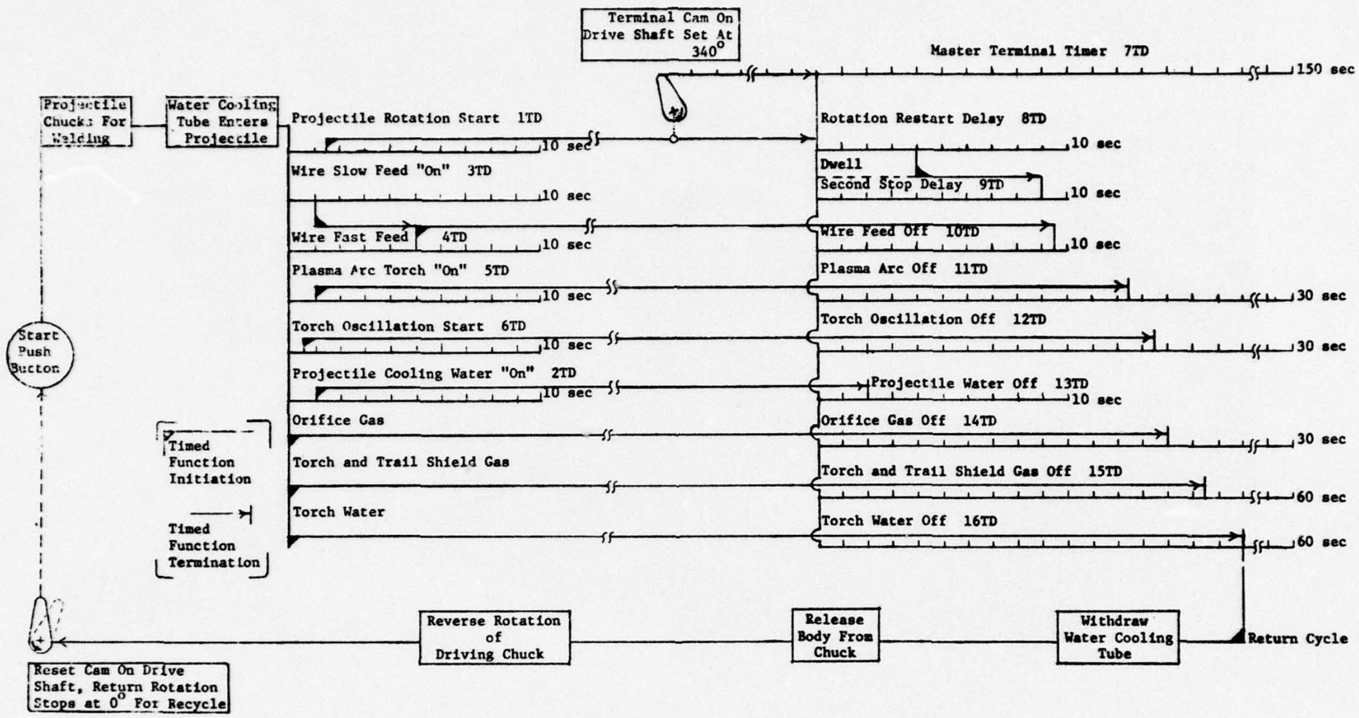


Figure 14. Timing Sequence for PAHW Overlay Band Machine

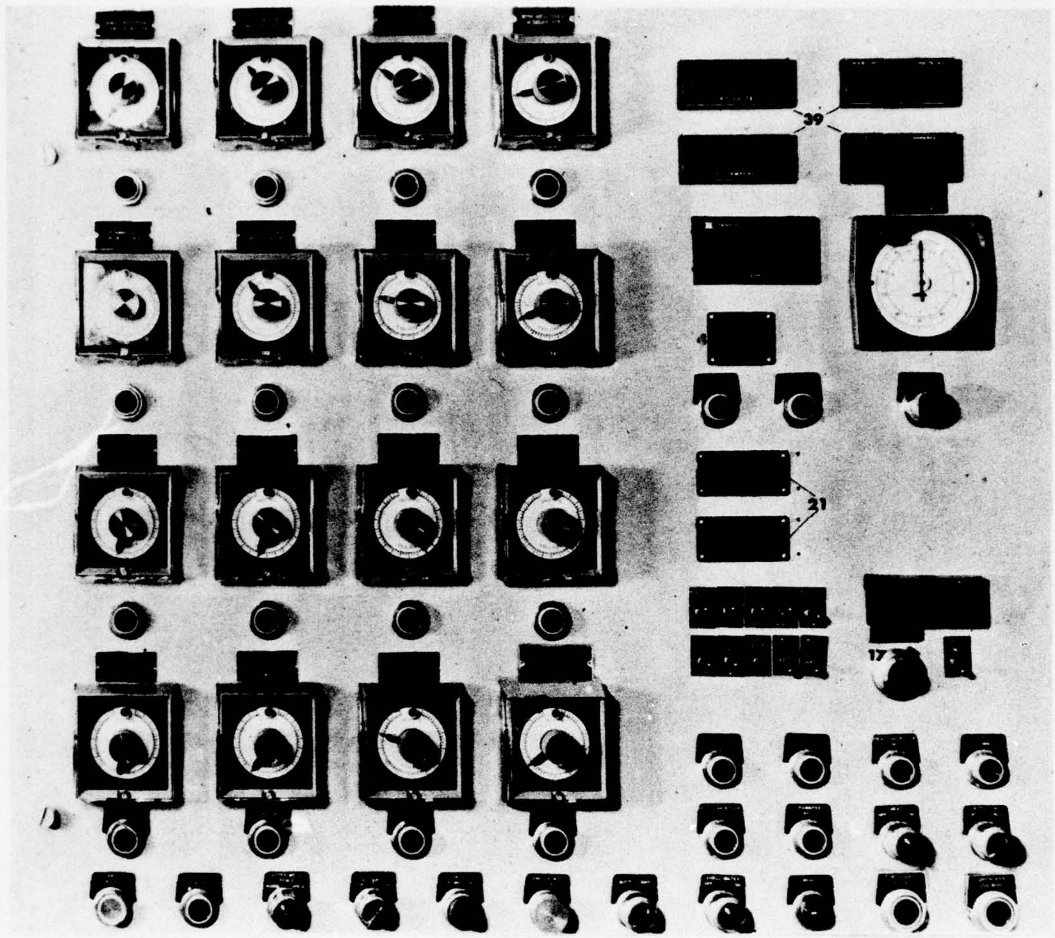


Figure 15. Control Panel Showing Timers, Push Buttons, Potentiometers and Switches for Automatic and Manual Operation.

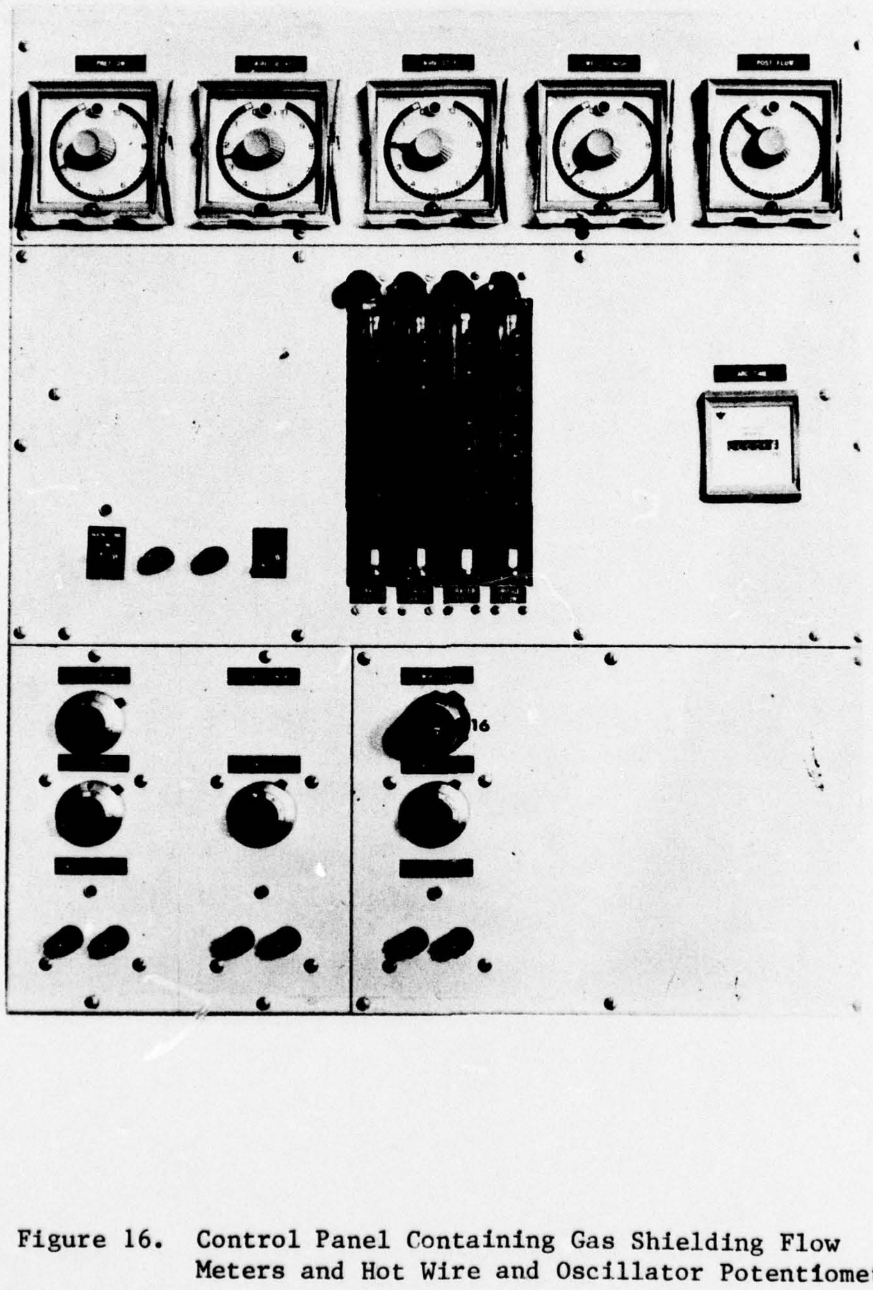


Figure 16. Control Panel Containing Gas Shielding Flow Meters and Hot Wire and Oscillator Potentiometers.

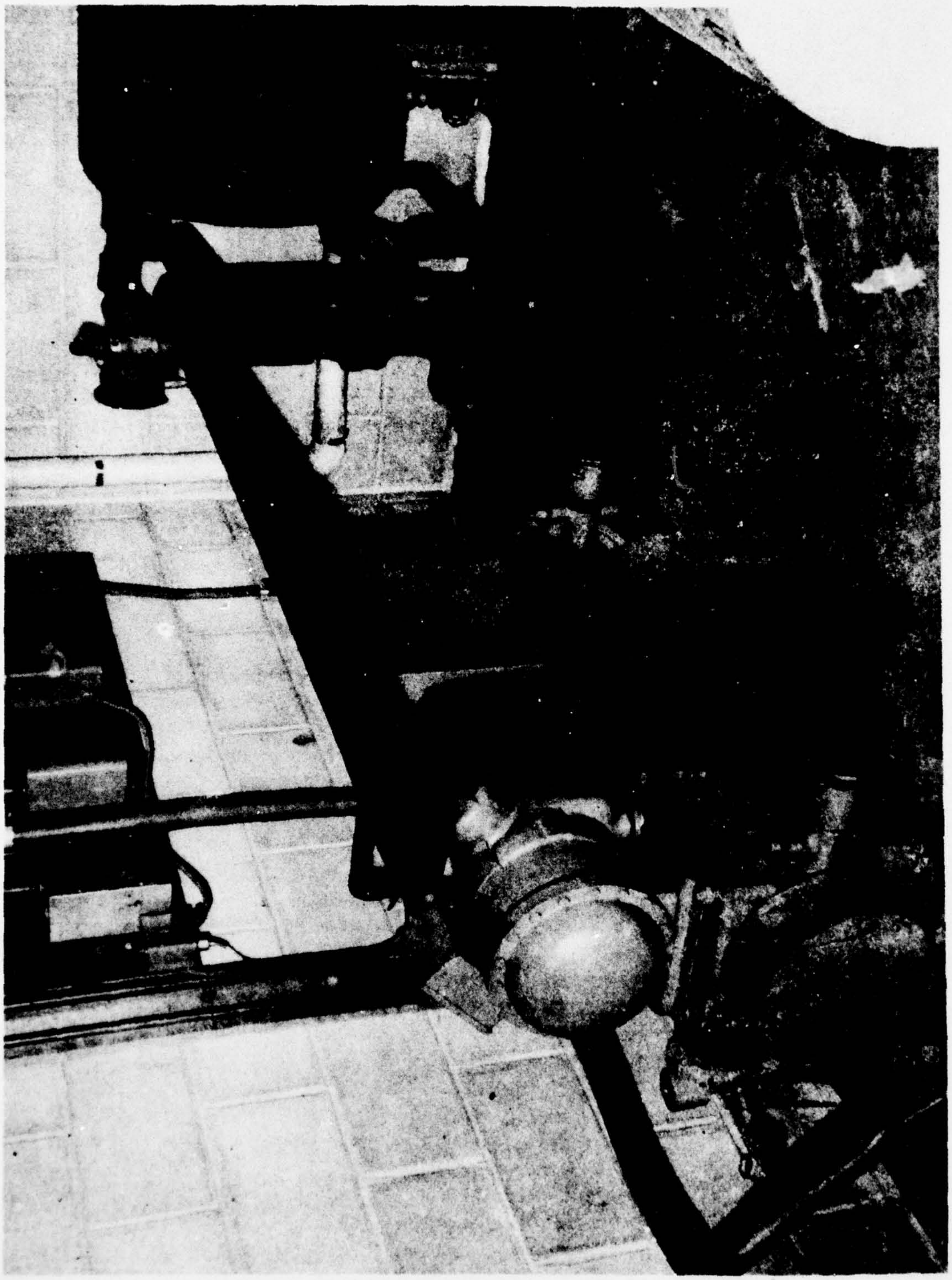


Figure 17. Chiller for Projectile Water Cooling.

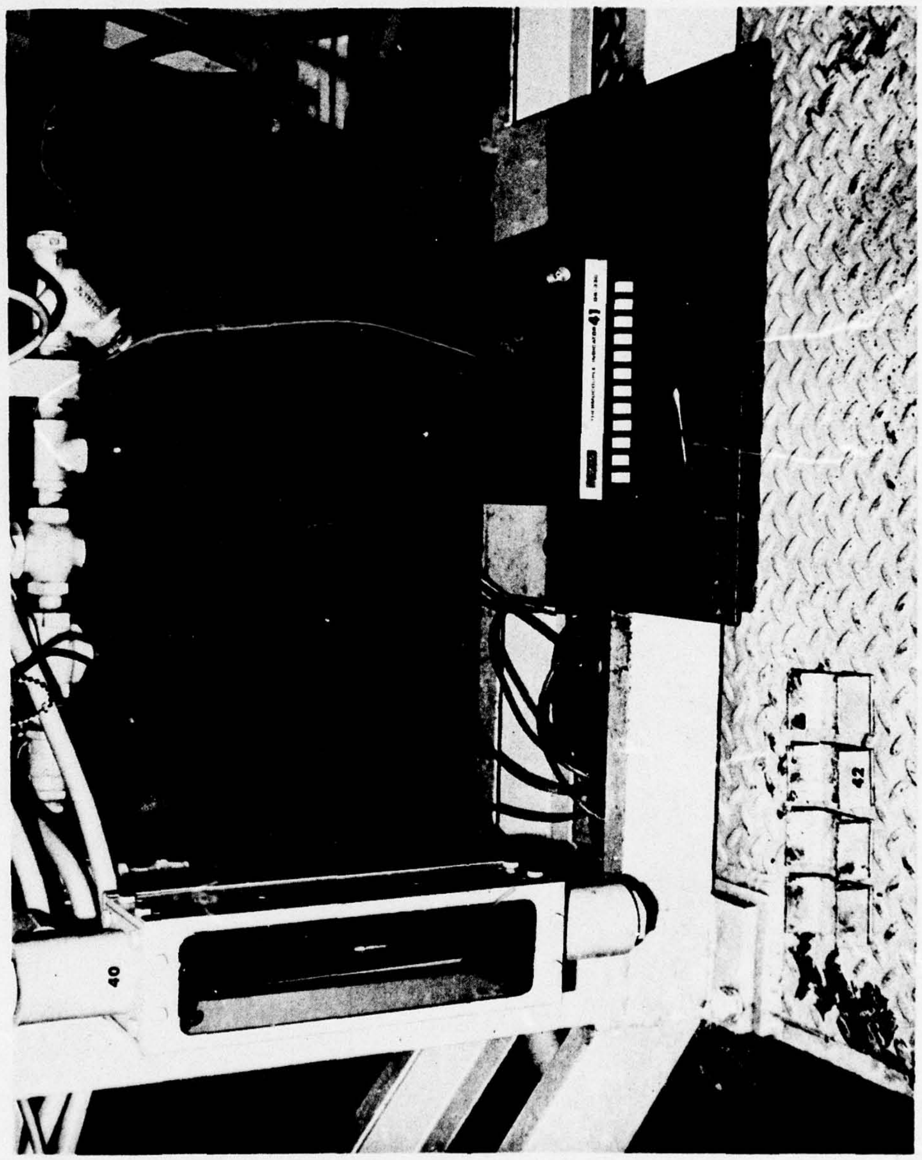


Figure 18. Projectile Water Flow Meter and Temperature Indicator and Heat Exchanger for Torch Water Cooling.